Carl Sagan / The Nuclear Winter.

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The Nuclear Winter
Carl Sagan
Carl Sagan, a modern-day Renaissance man of science, was horn in
1934 in New York. After graduating with both a B.A. and a B.S.
degree from the University of Chicago, Sagan completed his M.S.
in
physics and earned a Ph.D. in astronomy and astro-physics in
1960.
Sagan was nominated to join the Smithsonian Astrophysical
Observatory in 1962. At the same time, he also worked with the
Nobel-prize winner Joshna Lederberg, investigating the origins of
life on earth, and taught genetics at Stanford. Sagan then taught
astronomy at Harvard until 1968, when he became profossor of
astronomy and space sciences at Cornell University. He was then
appointed director of the laboratoy for Planetary Studies. Sagan
was
awarded the NASA medal for exceptional scientific achievement in
1972, after his hypotheses about Mars were validated by data
obtained from the 1971 Mars Mariner expedition. Beginning in
1968,
Sagan was editor of Icarus, the international journal of
astronomy,
and wrote many distinguished books. His works include The Cosmic
Connection (1973), which received the Campbell Award for best
science book; the Pulitzer-prize winning Dragons of Eden (1977);
Broca's Brain (1979), on developments in neurophysiology; and
Cosmos
(1980), which accompanied his widety-acclaimed television series.
In
"The Nuclear Winter" (1983), Sagan explored the unforeseen and
devastating physical and chemical effects of even a small-scale
nuclear war on the earth's biosphere and life on earth.

Except for fools and madmen, everyone knows that nuclear war would he
an
unprecedented human catastrophe. A more or less typical strategic
warhead
has a yield of 2 megatons, the explosive equivalent of 2 million tons
of
TNT. But 2 million tons of TNT is about the same as all the bombs
exploded
in World War II -- a single bomb with the explosive power of the entire
Second World War but compressed into a few seconds of time and an area
30
or 40 miles across …

In a 2-megaton explosion over a fairly large city, buildings would be
vaporized, people reduced to atoms and shadows, outlying structures
blown
down like matchsticks and raging fires ignited. And if the bomb were
exploded on the ground, an enormous crater, like those that can be seen
through a telescope on the surface of the Moon, would be all that
remained
where midtown once had been. There are now more than 50,000 nuclear
weapons, more than 13,000 megatons of yield, deployed in the arsenals

of
      the United States and the Soviet Union -- enough to obliterate a
million
      Hiroshimas.

      But there are fewer than 3000 cities on the Earth with populations of
      100,000 or more. You cannot find anything like a million Hiroshimas to
      obliterate. Prime military and industrial targets that are far from
cities
      are comparatively rare. Thus, there are vastly more nuclear weapons
than
      are needed for any plausible deterrence of a potential adversary.

      Nobody knows, of course, how many megatons would be exploded in a real
      nuclear war. There are some who think that a nuclear war can be
      "contained," bottled up before it runs away to involve much of the
world's
      arsenals. But a number of detailed analyses, war games run by the U.S.
      Department of Defense, and official Soviet pronouncements all indicate
      that this containment may be too much to hope for: Once the bombs begin
      exploding, communications failures, disorganization, fear, the
necessity
      of making in minutes decisions affecting the fates of millions, and the
      immense psychological burden of knowing that your own loved ones may
      already have been destroyed are likely to result in a nuclear paroxysm.
      Many investigations, including a number of studies for the U.S.
      government, envision the explosion of 5,000 to 10,000 megatons -- the
      detonation of tens of thousands of nuclear weapons that now sit
quietly,
      inconspicuously, in missile silos, submarines and long-range bombers,
      faithful servants awaiting orders.

      The World Health Organization, in a recent detailed study chaired by
Sune
      K. Bergstrom (the 1982 Nobel laureate in physiology and medicine),
      concludes that 1.1 billion people would be killed outright in such a
      nuclear war, mainly in the United States, the Soviet Union, Europe,
China
      and Japan. An additional 1.1 billion people would suffer serious
injufles
      and radiation sickness, for which medical help would be unavailable. It
      thus seems possible that more than 2 billion people-almost half of all
the
      humans on Earth-would be destroyed in the immediate aftermath of a
global
      thermonuclear war. This would represent by far the greatest disaster in
      the history of the human species and, with no other adverse effects,
would
      probably be enough to reduce at least the Northern Hemisphere to a
state
      of prolonged agony and barbarism. Unfortunately, the real situation
would
      be much worse. In technical studies of the consequences of nuclear
weapons
      explosions, there has been a dangerous tendency to underestimate the
      results. This is partly due to a tradition of conservatism which
generally
      works well in science but which is of more dubious applicability when
the
      lives of billions of people are at stake. In the Bravo test of March 1,

1954, a 15-megaton thermonuclear bomb was exploded on Bikini Atoll. It had
about double the yield expected, and there was an unanticipated
last-minute shift in the wind direction. As a result, deadly radioactive
fallout came down on Rongelap in the Marshall Islands, more than 200
kilometers away. Most all the children on Rongelap subsequently developed
thyroid nodules and lesions, and other long-term medical problems, due to
the radioactive fallout.

Likewise, in 1973, it was discovered that high-yield airbursts will
chemically burn the nitrogen in the upper air, converting it into oxides
of nitrogen; these, in turn, combine with and destroy the protective ozone
in the Earth's stratosphere. The surface of the Earth is shielded from
deadly solar ultraviolet radiation by a layer of ozone so tenuous that,
were it brought down to sea level, it would be only 3 millimeters thick.
Partial destruction of this ozone layer can have serious consequences for
the biology of the entire planet.

These discoveries, and others like them, were made by chance. They were
largely unexpected. And now another consequence -- by far the most dire --
has been uncovered, again more or less by accident.

The U.S. Mariner 9 spacecraft, the first vehicle to orbit another planet,
arrived at Mars in late 1971. The planet was enveloped in a global dust
storm. As the fine particles slowly fell out, we were able to measure
temperature changes in the atmosphere and on the surface. Soon it became
clear what had happened:

The dust, lofted by high winds off the desert into the upper Martian
atmosphere, had absorbed the incoming sunlight and prevented much of it
from reaching the ground. Heated by the sunlight, the dust warmed the
adjacent air. But the surface, enveloped in partial darkness, became much
chillier than usual. Months later, after the dust fell out of the
atmosphere, the upper air cooled and the surface warmed, both returning to
their normal conditions. We were able to calculate accurately, from how
much dust there was in the atmosphere, how cool the Martian surface ought
to have been.

Afterwards, I and my colleagues, James B. Pollack and Brian Toon of NASA's
Ames Research Center, were eager to apply these insights to the Earth. In
a volcanic explosion, dust aerosols are lofted into the high atmosphere.
We calculated by how much the Earth's global temperature should decline
after a major volcanic explosion and found that our results (generally a

fraction of a degree) were in good accor4 with actual measurements.
Joining forces with Richard Turco, who has studied the effects of nuclear
weapons for many years, we then began to turn our attention to the
climatic effects of nuclear war. [The scientific paper, "Global
Atmospheric Consequences of Nuclear War," was written by R. P. Turco, 0.
B. Toon, T. P. Ackerman, J. B. Pollack and Carl Sagan. From the last names
of the authors, this work is generally referred to as "TTAPS."]

We knew that nuclear explosions, particularly groundbursts, would lift an
enormous quantity of fine soil particles into the atmosphere (more than
100,000 tons of fine dust for every megaton exploded in a surface burst).
Our work was further spurred by Paul Crutzen of the Max Planck Institute
for Chemistry in Mainz, West Germany, and by John Birks of the University
of Colorado, who pointed out that huge quantities of smoke would be
generated in the burning of cities and forests following a nuclear war.

Croundburst -- at hardened missile silos, for example -- generate fine
dust. Airbursts -- over cities and unhardened military installations --
make fires and therefore smoke. The amount of dust and soot generated
depends on the conduct of the war, the yields of the weapons employed and
the ratio of groundbursts to airbursts. So we ran computer models for
several dozen different nuclear war scenarios. Our baseline case, as in
many other studies, was a 5000-megaton war with only a modest fraction of
the yield (20 percent) expended on urban or industrial targets. Our job,
for each case, was to follow the dust and smoke generated, see how much
sunlight was absorbed and by how much the temperatures changed, figure out
how the particles spread in longitude and latitude, and calculate how long
before it all fell out in the air back onto the surface. Since the
radioactivity would be attached to these same fine particles, our
calculations also revealed the extent and timing of the subsequent
radioactive fallout.

Some of what I am about to describe is horrifying. I know, because it
horrifies me. There is a tendency -- psychiatrists call it "denial" -- to
put it out of our minds, not to think about it. But if we are to deal
intelligently, wisely, with the nuclear arms race, then we must steel
ourselves to contemplate the horrors of nuclear war.

The results of our calculations astonished us. In the baseline case, the
amount of sunlight at the ground was reduced to a few percent of
normal-much darker, in daylight, than in a heavy overcast and too dark for
plants to make a living from photosynthesis. At least in the Northern
Hemisphere, where the great preponderance of strategic targets lies, an
unbroken and deadly gloom would persist for weeks.

Even more unexpected were the temperatures calculated. In the baseline
case, land temperatures, except for narrow strips of coastline, dropped
to
minus 250 Celsius (minus 13 degrees Fahrenheit) and stayed below
freezing
for months -- even for a summer war. (Because the atmospheric structure
becomes much more stable as the upper atmosphere is heated and the low
air
is cooled, we may have severely underestimated how long the cold and
the
dark would last.) The oceans, a significant heat reservoir, would not
freeze, however, and a major ice age would probably not be triggered.
But
because the temperatures would drop so catastrophically, virtually all
crops and farm animals, at least in the Northern Hemisphere, would be
destroyed, as would most varieties of uncultivated or domesticated food
supplies. Most of the human survivors would starve.

In addition, the amount of radioactive fallout is much more than
expected.
Many previous calculations simply ignored the intermediate time-scale
fallout. That is, calculations were made for the prompt fallout -- the
plumes of radioactive debris blown downwind from each target-and for
the
long-term fallout, the fine radioactive particles lofted into the
stratosphere that would descend about a year later, after most of the
radioactivity had decayed. However, the radioactivity carried into the
upper atmosphere (but not as high as the stratosphere) seems to have
been
largely forgotten. We found for the baseline case that roughly 30
percent
of the land at northern midlatitudes could receive a radioactive dose
greater than 250 rads, and that about 50 percent of northern
midlatitudes
could receive a dose greater than 100 rads. A 100-rad dose is the
equivalent of about 1000 medical X-rays. A 400-rad dose will, more
likely
than not, kill you.

The cold, the dark and the intense radioactivity, together lasting for
months, represent a severe assault on our civilization and our species.
Civil and sanitary services would be wiped out. Medical facilities,
drugs,
the most rudimentary means for relieving the vast human suffering,
would
be unavailable. Any but the most elaborate shelters would be useless,
quite apart from the question of what good it might be to emerge a few
months later. Synthetics burned in the destruction of the cities would
produce a wide variety of toxic gases, including carbon monoxide,
cyanides, dioxins and furans. After the dust and soot settled out, the
solar ultraviolet flux would be much larger than its present value.
Immunity to disease would decline. Epidemics and pandemics would be
rampant, especially after the billion or so unburied bodies began to
thaw.
Moreover, the combined influence of these severe and simultaneous
stresses
on life are likely to produce even more adverse consequences --
biologists
call them synergisms -- that we are not yet wise enough to foresee.

So far, we have talked only of the Northern Hemisphere. But it now seems -
unlike the case of a single nuclear weapons test -- that in a real nuclear
war, the heating of the vast quantities of atmospheric dust and soot in
northern midlatitudes will transport these fine particles toward and
across the Equator. We see just this happening in Martian dust storms. The
Southern Hemisphere would experience effects that, while less severe than
in the Northern Hemisphere, are nevertheless extremely ominous. The
illusion with which some people in the Northern Hemisphere reassure
themselves -- catching an Air New Zealand flight in a time of serious
international crisis, or the like -- is now much less tenable, even on the
narrow issue of personal survival for those with the price of a ticket.

But what if nuclear wars can be contained, and much less than 5000
megatons is detonated? Perhaps the greatest surprise in our work was that
even small nuclear wars can have devastating climatic effects. We
considered a war in which a mere 100 megatons were exploded, less than one
percent of the world arsenals, and only in low-yield airbursts over
cities. This scenario, we found, would ignite thousands of fires, and the
smoke from these fires alone would be enough to generate an epoch of cold
and dark almost as severe as in the 5000 megaton case. The threshold for
what Richard Turco has called The Nuclear Winter is very low.

Could we have overlooked some important effect? The carrying of dust and
soot from the Northern to the Southern Hemisphere (as well as more local
atmospheric circulation) will certainly thin the clouds out over the
Northern Hemisphere. But, in many cases, this thinning would be
insufficient to render the climatic consequences tolerable -- and every
time it got better in the Northern Hemisphere, it would get worse in the
Southern.

Our results have been carefully scrutinized by more than 100 scientists in
the United States, Europe and the Soviet Union. There are still arguments
on points of detail. But the overall conclusion seems to be agreed upon:
There are severe and previously unanticipated global consequences of
nuclear war-subfreezing temperatures in a twilit radioactive gloom lasting
for months or longer.

Scientists initially underestimated the effects of fallout, were amazed
that nuclear explosions in space disabled distant satellites, had no idea
that the fireballs from high-yield thermonuclear explosions could deplete
the ozone layer and missed altogether the possible climatic effects of

nuclear dust and smoke. What else have we overlooked?

Nuclear war is a problem that can be treated only theoretically. It is not
amenable to experimentation. Conceivably, we have left something important
out of our analysis, and the effects are more modest than we calculate. On
the other hand, it is also possible-and, from previous experience, even
likely-that there are further adverse effects that no one has yet been
wise enough to recognize. With billions of lives at stake, where does
conservatism lie-in assuming that the results will be better than we
calculate, or worse?

Many biologists, considering the nuclear winter that these calculations
describe, believe they carry somber implications for life on Earth. Many
species of plants and animals would become extinct. Vast numbers of
surviving humans would starve to death. The delicate ecological relations
that bind together organisms on Earth in a fabric of mutual dependency
would be torn, perhaps irreparably. There is little question that our
global civilization would be destroyed. The human population would be
reduced to prehistoric levels, or less. Life for any survivors would be
extremely hard. And there seems to be a real possibility of the extinction
of the human species.

It is now almost 40 years since the invention of nuclear weapons. We have
not yet experienced a global thermonuclear war -- although on more than
one occasion we have come tremulously close. I do not think our luck can
hold forever. Men and machines are fallible, as recent events remind us.
Fools and madmen do exist, and sometimes rise to power. Concentrating
always on the near future, we have ignored the long-term consequences of
our actions. We have placed our civilization and our species in jeopardy.

Fortunately, it is not yet too late. We can safeguard the planetary
civilization and the human family if we so choose. There is no more
important or more urgent issue.
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